SECOND QUARTERLY PROGRESS REPORT

PLANNING, EVALUATION, AND ANALYTICAL STUDIES IN PLANETARY QUARANTINE AND SPACECRAFT STERILIZATION

EXOTECH
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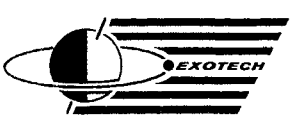

SECOND QUARTERLY PROGRESS REPORT

PLANNING, EVALUATION, AND ANALYTICAL STUDIES IN PLANETARY QUARANTINE AND SPACECRAFT STERILIZATION

Prepared under
Contract NASw - 2062

For
National Aeronautics and Space Administration
Headquarters
Planetary Quarantine Office

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by

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CONTENTS

I. INTRODUCTION AND SUMMARY

This report covers progress for the three month period ending September 30, 1970. In accordance with the terms of contract NASw-2062, it reports status and progress on five tasks, viz.,

- Quarantine Document System for Planetary Flight Missions - Task 2
- Planning of Supporting Technology Transfer - Task 4
- Analysis of Microbial Release Probabilities - Task 5
- Analytical Models for the Design of Heat Sterilization Cycles - Task 6
- Organic Constituent Inventory for Planetary Flight Missions - Task 7

Quarantine Document System for Planetary Flight Missions - This information system is intended to provide rapid access to material relating to, (a) formulation of Planetary Quarantine requirements for flight missions, and (b) the review and apporval of flight project quarantine plans. The system is in operation and has been extensively used in compiling information for the review of PQ requirements and of project plans for Mariner Mars '71, Pioneer F/G and Viking '75. (See page 3)

Planning of Supporting Technology Transfer - The principal purpose of this task is to investigate the transfer of supporting technology developed by the NASA Planetary Quarantine Office. During this reporting period assistance was provided for a briefing to the U.S. Army Research and Development Command and its contractors on NASA-sponsored advances in sterilization technology with possible application to field hospitals of the Army of the 1980's. (See page 4)

Analysis of Microbial Release Probabilities – The objective of this task is to develop the analytical basis for including the probability of release in the determination by flight projects of heat sterilization requirements. Microbial release resulting from high velocity impact was analyzed further using experimental data extracted from test results of impact experiments conducted by the Boeing Company. This work has provided a basis for the evaluation of a reasonable upper bound for the probability of release due to high velocity impact. Additional work remains, however, to quantify release probabilities due to aeolian erosion. (See page 5)

Analytical Models for the Design of Heat Sterilization Cycles – Three models designed to facilitate flight project implementation of planetary quarantine requirements were developed or updated and exercised. Two criteria for the evaluation of least stress oven profiles in terminal dry heat sterilization were evaluated using our thermal dynamics sterilization model. Profiles involving temperature plateaus were shown to be superior in minimizing overkill. (See page 10) A solution to the water diffusion model of a spore based upon Fourier expansion techniques has been formulated for application to several cases where the spore is embedded in a diffusion impeding medium. (See page 15) A third model relating the processes of microorganism growth and proliferation after release on a planet has been developed and will be used in evaluating the impact upon sterilization programs of changes in the value of the probability of growth. (See page 19)

Organic Constituent Inventory for Planetary Flight Missions – The objective of this task is to establish the feasibility and general characteristics of an information system on organic/chemical contamination of the planets. Estimates of the potential interference of contamination with scientific missions to the planets are being obtained through correspondence with the Viking '75 science team. The control and accountability of organic constituents in the

Viking Project is being studied to ascertain its applicability, wholly or in part, to the chemical contamination problem confronting subsequent missions to the planets. More complete details are presented on page 22.

Details regarding these five tasks are presented in the following sections.

II. QUARANTINE DOCUMENT SYSTEM FOR PLANETARY FLIGHT MISSIONS

A. Objective

The objective of this task is the design, implementation and operation of a storage-retrieval system of information pertinent to the establishment of flight project planetary quarantine requirements and the review of flight project quarantine plans and related operations. Copies of the plans, their supplements and revisions, supporting reports, approval request memos, approval status, and reported operational data relating to planetary quarantine are to be acquired, catalogued, and indexed in a rapid retrieval system for each active flight program.

B. Progress

The system has been designed, implemented and is now in operation. (See Quarterly Report of May 30, 1970 for design details.) The collection is rapidly growing and currently numbers 110 documents relating to six flight programs. The thesaurus used in indexing these documents to facilitate retrieval of specified information is similarly expanding. More than 300 terms and subterms have been accumulated in this thesaurus by indexing incoming documents based upon anticipated inquiries. An effort is

currently underway to standardize these terms and to arrange them in a simplified hierarchy. These changes will permit indexing and retrieval functions to be transfered to other personnel without affecting operational efficiency.

All processing is manual and will probably remain so unless collection size or utilization increase significantly. More than 20 retrievals have been effected relating to review of Viking '75, Mariner Mars '71 and Pioneer F/G Planetary Quarantine plans.

During the next reporting period, a request accounting system will be established. Effort will continue on thesaurus development. A manual describing the system and its operation will be prepared.

III. PLANNING OF SUPPORTING TECHNOLOGY TRANSFER

A. Objective

The objective of this task is to identify new applications of technology developed by NASA's Planetary Quarantine Office and to facilitate its transfer. Potential applications include flight project implementation of planetary quarantine and sterilization requirements as well as non-space related fields.

B. Progress

Assistance was provided for the NASA briefing on August 11, 1970 of members of the U. S. Army Medical Research and Development Command and its contractors on NASA—sponsored advances in sterilization technology. The purpose of this meeting was to identify and describe those advances with possible application to the operations of the Army field hospitals of the 1980's.

Mr. S. Schalkowsky of Exotech, Dr. J. Stern of Bionetics, Prof. I. Pflug of the University of Minesota and Dr. M. Reynolds of Sandia discussed results of recent NASA—sponsored work in sterilization by means of dry heat, gaseous and liquid agents and thermal radiation. Methods for the design, control and monitoring of sterilization processes using these techniques were presented.

The applicability of this technology is currently under review by Lt. Col. H. Johnson and her staff and the need for additional information will be determined by their assessment.

IV. ANALYSIS OF MICROBIAL RELEASE PROBABILITIES

A. Objective

The objective of this task is to develop a recommended approach for the inclusion of microbial release probability in flight project implementation of heat sterilization cycles. These probabilities are associated with fracturing of planetary probe materials due to high velocity impact on the surface of a planet and to post-landing (or impact) erosion of such materials during the quarantine period.

B. Progress

Work during the reporting period focused on the quantification of fracture-related parameters of the release model. In particular, it was of interest to establish whether magnitudes for the fracture ratio, $f(V)$, and survival during impact, $g(V)$, inherent in the laboratory data from the Boeing Company[1] are consistent with the desired upper bounds for these

[1] Fraser, S.J.; Olson, R.L.; and Green, R.H.: Microbial Release from Solids after Simulated Hard Landings. Paper presented at the COSPAR Meeting, Leningrad, May 1970.

parameters derived in our earlier sensitivity analyses[2]. Specifically, it was found that the following limits are of interest:

Intermediate Impact Velocities ($V_I \approx 1,500$ fps):

$f(V_I)$ – not critical, could be assumed = 10^6 $1/m$

$g(V_I)$ – = 10^{-1}

High Impact Velocities ($V_H \approx 3,100$ fps):

$f(V_H) \cdot g(V_H) = 10^3$ $1/m$

The Boeing data provided information on the fraction of microorganisms which survived impact at different velocities, with measurements either of the total population initially placed within the pellets or of those released during impact. This information can be analyzed in terms of the parameters of interest through the relationship,

$$P(r) = \frac{\text{number surviving}}{\text{initial population}} = f(V) \cdot g(V) \cdot \lambda$$

where λ is the exposure depth coefficient[3] previously determined to be 3×10^{-6} m. Values for $f(V)$ were obtained through measurements of fragments of impacted pellets supplied to us by the Boeing Company. The reported results of the Boeing experiments provided values for the percentages of spores surviving impact and released at impact. Our analysis of these data with respect to the release model is summarized in Table 1.

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[2] Schalkowsky, S.; and Levy, P.S.: Estimation of Microbial Release Probabilities from a Martian Lander. Tech. Report TR 70-02, (contract NASw-2062), Exotech Systems, Inc., Washington, D.C., July 1970.

[3] Peterson, N.J.; Cornell, R.G.; and Puleo, J.R.: Release of Microbial Contamination from Fractured Solids. Space Life Sci., vol. 1, no. 4, March 1969, pp. 531-537.

TABLE 1. RELEASE MODEL PARAMETERS EVALUATED WITH IMPACT EXPERIMENT DATA

VELOCITY	EXPERIMENT DATA (averaged)			CALCULATED DATA			
	$g(V)_{ave}$	$f(V)$	$P(r)_{impact}$	$g(V)_{surf}$	$g(V)_{ave} / g(V)_{surf}$	$g(V)_{ave} \cdot f(V)$	$g(V)_{surf} \cdot f(V)$
1,500 fps	0.56	10^5	4.8×10^{-3}	.016	35	5.6×10^4	1.6×10^3
3,100 fps	.09	10^4	3.8×10^{-3}	.127	0.71	9×10^2	1.3×10^3

Our results for the fracture ratio and probability of survival during impact were found to be consistent with the limits described above for intermediate (1,500 fps) and high velocity (3,100 fps) impacts, i.e.,

$$\text{For impacts at 1,500 fps: } f(V_I) \approx 10^5$$

$$g(V_I) \approx 2 \times 10^{-2}$$

and for impacts at 3,100 fps:

$$f(V_H) \cdot g(V_H) = (0.9 - 1.3) \cdot 10^3 \text{ 1/m}$$

An important result of this study is the validation of the values for $f(V)$ and $g(V)$ used in the sensitivity analysis of the model for probability of release due to impact[2]. The earlier analysis was based on the assumption that the value of the product $g(V) \cdot f(V)$ is of the order of 10^3. The results of the Boeing work show that it is reasonable to use 3,100 ft/sec as the hard-landing velocity. Corresponding to that velocity, the product $g(V_H) \cdot f(V_H)$ attains a maximum value; at higher velocities the exposure of area is somewhat increased, but $g(V)$ reduces significantly. Increases in velocity above 3,100 ft/sec cause pulverization of the material and thermal fusing of particles while for lower velocities the product $g(V) \cdot f(V)$ is definitely smaller.

The fracture ratio values were obtained from our measurements of samples provided by the Boeing Company. The fragments of the fractured pellets were passed through a series of graduated sieves and each size class of particles was weighed. The fragments were assumed to be spherical and the total newly exposed surface area was calculated for each pellet. The spherical approximation for fragments provides a lower bound for the fracture ratio. This is consistent with the purpose of the analysis, i.e., to show

the reality of the fracture ratio parameter of the release model and to bound its magnitude for the various impact velocities. The measurement and calculation was done for three (3) pellets at each impact velocity and in each case yielded results within 5 percent of the following:

Velocity, ft/sec	Fracture Ratio
1,500	10^5
3,100	10^4
5,100	0.5×10^5

The total probability of release of buried contamination is partitioned into release due to impact and release due to aeolian erosion. The preceding discussion together with the results of the previously reported sensitivity analysis[2] provide a basis for evaluation of a reasonable upperbound for the impact component of the probability of release at given impact velocities.

To continue the course of study in this task a similar analysis is required for the erosion component. In preparation for analysis of the erosion component of the microbial release model, R. Lyle of our staff visited in Seattle with Dr. Green of JPL and Dr. Olson of the Boeing Company to ensure compatibility of effort and timely exchanges of analytical and experimental results. As a result of this informal liaison we reviewed plans for the Boeing Company experiments on release of buried microorganisms through erosion of specimens. The results of these experiments are expected to provide useful data for future analytical work.

The erosion experiment data will not be available during the next quarter; however, in that period we will formulate the $P_b(r)$ requirement for a flight project so that the only unknowns will be erosion parameters.

V. ANALYTICAL MODELS FOR THE DESIGN OF HEAT STERILIZATION CYCLES

A. Objective

The objective of this task is to develop new analytical models or to updata existing models in order to facilitate the flight project implementation of planetary quarantine requirements. These models are intended to bring to bear new laboratory data and/or the results of newly developed technology.

B. Progress

During the reporting period, work was performed in the four areas described below.

1. Thermal Dynamics in Heat Sterilization

The previous quarterly report presented both the overall objective of this investigation and the mathematical model selected for the analysis. It should be noted that this investigation presents only a methodology and not specific results for a particular dry heat sterilization cycle.

Alternatives of oven profiles were studied to find a basis for selecting an optimal profile which provides a significant reduction in the excessive heat exposure of low thermal inertia components without significantly increasing the total heating time required to meet the desired reduction of buried microbial load in high inertia components.

Two major types of oven profiles were investigated:

(a) Profiles involving plateaus (hold periods in the heat-up phase of the cycle) at selected temperatures below the 125^{o} level (i.e., the sterilization temperature), and

(b) Profiles involving a number of short duration temperature "dips" on the 125° C plateau.

The parameters in the first category are the number of the plateaus, their levels and durations, and the rate of heating between the plateaus. In the second category the variables are the number of "dips," their depth, and duration. Combinations of these two categories were also investigated.

The previous quarterly report presented an explanation of the use of total lethalities, and differences between total lethalities as measures of effectiveness in tailoring oven profiles. Excess total lethality (overkill) in low thermal inertia components is, in this context, an indicator of excessive heat exposure during the sterilization cycle. The three (3) oven heating profiles previously developed and described in the first quarterly report were used as reference profiles for comparative evaluation of the results obtained during the present reporting period.

Work in this phase of the task began with the preparation of a reference profile for the oven and for a component having a thermal time constant (τ) of 1.2 hours. The reference heating cycle and all subsequent profiles were designed for a six (6) decade reduction of buried microbial load in the high thermal inertia component. This reduction was achieved in 9.6 hours in the referenced case with an overkill in the low thermal inertia component (represented by the oven temperature profile, $\tau = 0$) of 3.10 decades.

Efforts to reduce the overkill of the reference heat sterilization cycle began with an examination of the case of an oven profile with one plateau at 100° C. The duration of the plateau was allowed to vary from .8 to 4 hours while the heating rate from this plateau to the 125° C level varied from 12.5 to 50° C/hr. The results, a sample of which is shown in Table 2,

indicated that a slow heating rate between the plateaus (12.5°C/hr) is the more effective in reducing overkill without a significant time penalty. It was also shown that for plateau durations over 1.2 hrs, the marginal benefit is insignificant. Hence, for this particular profile, a 0.8 – 1.2 hrs plateau duration and a 12.5°C/hr heating rate between plateaus represents the optimum.

TABLE 2

HEATING PROFILE WITH ONE HOLD PERIOD IN HEAT-UP PHASE

Plateau Duration	Overkill	Total Time
0 (reference)	3.10	9.6
.8	2.08	13.0
1.2	2.07	13.2
1.6	2.07	13.6

In an effort to reduce further the temperature difference between the external and internal (low and high thermal inertial) components, an oven profile with two intermediate plateaus was tested (one plateau at 90°C and another at 110°C). The ranges for plateau duration and heating rate between plateaus were the same as in the previous case. In general, the introduction of a second plateau gave improved results. Further reduction in overkill was achieved without a significant increase of the total time. As in the previous case, the lower heating rate between plateaus (i.e., 12.5°C/hr) proved to be marginally beneficial. Duration of the plateaus over 1.8 hrs does not reduce overkill significantly but does increase total time substantially (Table 3).

TABLE 3

HEATING PROFILE WITH TWO HOLD PERIODS IN HEAT-UP PHASE

Plateau Duration	Overkill	Total Time
0 (reference)	3.10	9.6
.6	2.044	11.4
1.2	1.917	12.2
1.8	1.846	13.2
2.4	1.806	14.4
3	1.782	15.4

The addition of a third plateau caused a substantial increase in total time without a similar decrease in overkill as shown in Table 4.

TABLE 4

HEATING PROFILE WITH THREE HOLD PERIODS IN HEAT-UP PHASE

Plateau Duration	Overkill	Total Time
0 (reference)	3.10	9.6
1.2	1.80	13.8
1.8	1.75	15.4
2.4	1.72	17.0

Finally, an oven profile with short-duration temperature dips on the 125^{o}C plateau was tested. Heating to that level was performed at the fast rate of 50^{o}C/hr, thus creating a significant temperature lag between the internal and external components. This lag was tested and when found greater than 15^{o}C, the oven temperature was brought down to 115^{o}C and

held for a time period ranging from .2 to 1 hr. When the oven temperature was returned to the 125° C level, the temperature lag was tested again. This time a 10° C lag would call for a 5° C "dip." This procedure was carried on until the temperature difference between the external and internal components became less than 10° C. The results, shown in Table 5, indicate that this method is not as effective as the one employing intermediate plateaus. In the case of short duration dips (.2 and .4 hrs) the results are poorer than those obtained for the referenced case, while with dips of long duration the reduction in overkill is rather insignificant.

TABLE 5

HEATING PROFILE WITH INTERMITTENT COOLING

Length of Step Down (hr)	Overkill	Total Time
0 (reference)	3.10	9.6
.2	3.18	10.00
.4	3.11	10.40
.6	3.00	10.40
.8	2.81	10.40
1	2.87	10.40

The results of this investigation indicate that the use of two intermediate plateaus of a duration ranging from 1 to 2 hrs and a slow heating rate between the plateaus (10 – 12.5° C/hr) provide an improved oven profile which effectively reduces overkill without increasing significantly the total time of the heating cycle.

Temperature "dips" from the 125° C level are effective only in cases where there exists a significant temperature difference between the internal and external components. In the case of intermediate plateaus, this temperature gap is not allowed to develop and hence combining the two types of oven profiles is not effective. In general, the method of employing intermediate

plateaus is more efficient in minimizing overkill in an acceptable time cycle. For the case examined, two plateaus, each of a 1.8 hr duration, at 90^{o} C and 110^{o} C with slow rate of heating (i.e., 10^{o}/hr) between them provide the best oven profile. In this case we obtained six decades reduction for the high thermal inertial component during 13.8 hr total time and incurred 1.80 decades overkilling in the low inertia component.

A flow chart and computer program for the calculations performed in this task are appended.

During the final phase of this task, optimal oven profiles will be developed for an increased range of thermal time constant (τ) values to enhance the evaluation of the methodology's applicability to the actual range of components and materials of space vehicles.

2. Microbial Resistance (Diffusion Model)

The first quarterly report described efforts directed toward modifying the existing mathematical diffusion model for applicability to buried sources. This modification involved the development of a two region diffusion model suitable for evaluating the water content and diffusion in an impeding medium. In the model concept a spore of radius b was centered at the origin of a coordinate system. The water concentration at a distance r from the origin at time t was denoted by C(r,t). The diffusion relationship, assumed valid inside and outside the spore is

$$\frac{\partial C}{\partial t} = D\left[\frac{\partial^2 C}{\partial r^2} + \frac{2}{r}\frac{\partial C}{\partial r}\right] \qquad (1)$$

where D is a region-dependent diffusion coefficient. Although the same mathematics apply inside and outside the spore, the diffusion coefficients are permitted to differ.

Further, the diffusion relationship was shown to be subject to the conditions

$$C(r, 0) = F(r) \tag{2}$$

$$C(R, t) = \text{constant} \tag{3}$$

$$\frac{\partial C}{\partial r}\Bigg|_{r = 0} = 0 \tag{4}$$

$$\frac{D(\text{spore})}{D(\text{medium})} \quad \frac{\partial C}{\partial r}\Bigg|_{b^-} = \frac{\partial C}{\partial r}\Bigg|_{b^+} \tag{5}$$

Where R represents a distance outside the spore at which the water concentration is assumed constant.

Equation (1) was then evaluated using a difference equation approximation. The radius R was divided into M increments Δr, $\Delta r = \frac{R}{M}$, and the time increment set as Δt.

The difference equation method, however, was found in the analysis of this period to contain two inherent limitations. First, in order to assure a realistic approximation of the differential equation, Δr and Δt must both approach zero, i.e., be small. Second, they must satisfy the relationship

$$0 < D \quad \frac{\Delta t}{(\Delta r)^2} \leq \frac{1}{2} \tag{6}$$

in both regions to insure convergence of the finite difference representation. The extent to which these conditions are restrictive depends upon the values of the diffusion coefficient inside and outside the spore. The diffusion

coefficient inside the spore is typically 10^{-6} cm^2/sec or less[4]. If Δr is set at $.2 \times 10^{-4}$ cm, approximately 1/5 of the spore's radius, then Δt must be less than 2×10^{-4} second. This value is itself rather restrictive. However, given a diffusion coefficient in the external medium of 10^{-4} or greater, Δt must be less than 2×10^{-6} second to satisfy (6). The end result is an excessive amount of computer time.

When the diffusion coefficient in the external medium is much larger than that in the spore, say by a factor of 10^2, we can introduce a method independent of Δt. For this great a difference the water diffuses much faster through the medium than through the spore. Therefore, the value of R in condition (3) approaches b, the spore boundary. The initial and boundary conditions then become

$$C(r, 0) = F(r) \tag{7}$$

$$C(b, t) = \text{constant} \tag{8}$$

$$\frac{\partial C}{\partial r}\Bigg|_{r=0} = 0 \tag{9}$$

The problem now concerns only one region and the diffusion relationship can be solved analytically. A group of solutions of the form

$$C(r, t) = B \frac{\sin \omega r}{r} e^{-D\omega^2 t} \tag{10}$$

results where ω is a real constant greater than zero and B an arbitrary constant. There exists an infinity of such solutions which satisfy the boundary conditions: those for which $\sin \omega b = 0$, i.e., $\omega = \frac{n\pi}{b}$.

[4]Barrett, M.J.: Investigations into a Diffusion Model of Dry Heat Sterilization. Interim Report, (contract NASw-1734), Exotech Inc., Systems Res. Div., May 5, 1969.

A superposition of these solutions yields

$$C(r, t) = \frac{1}{r} \sum_{n=1}^{\infty} B_n \sin \frac{n\pi r}{b} \left(\exp \frac{-Dn^2 \pi^2}{b^2} t \right) + C_o \qquad (11)$$

where C_o represents the constant water concentration outside the spore. If $C(r, t)$ is to satisfy (7)

$$C(r, t) = F(r) = \frac{1}{r} \sum_{n=1}^{\infty} B_n \sin \frac{n\pi t}{b} + C_o \qquad (12)$$

then

$$B_n = \frac{2}{b} \int_o r' \left[F(r') - C_o \right] \sin \frac{n\pi r'}{b} \, dr' \qquad (13)$$

Assuming the initial water concentration to be uniform in the spore at $t = 0$, equation (13) yields

$$B_n = \left[C_o - F \right] \frac{b^2 \cos n\pi}{n\pi} \qquad (14)$$

Equation (11) can now be solved by computer. The solution could include, perhaps, the first one hundred terms of the series since the successive contributions to the sum approach zero as n becomes large. While this may seem a large number of calculations consider that it can be done for any value of t greater than zero. The series solution, while independent of time increments, contains limitations not found in the difference equation solution. It does not lend itself, for example, to variations of the diffusion coefficient, a temperature dependent quantity, with time. It also assumes the value of D in the spore to be much less than in the external medium, which may not be true in many media. To overcome this difficulty other numerical methods are under consideration.

During the next reporting period, it is planned to apply the techniques discussed above to a number of situations occurring in heat sterilization. Specifically, the mathematical boundary conditions that describe (a) buried spores, (b) spores between mated surfaces, and (c) spores on exposed surfaces will be developed in a parallel set of studies. It is anticipated that application of these boundary conditions will result in equations analogous to Equation (11), but with more insight provided into the coefficients B_n and thereby to a solution of the water diffusion problem.

To evaluate the accuracy of the Fourier expansion analysis described above, it is necessary to obtain data on the physical characteristics of media such as lucite, steel, and others in use in experiments reported in spore studies. A collection of experimental results against which the theoretical effort can be measured, will permit more confidence in the mathematical techniques described above. These efforts will be undertaken during the next reporting period.

3. Microbial Proliferation (Probability of Growth)

During this reporting period existing models for the estimation of the probability of microbial growth on a planet were extended to support current interest in the re-evaluation of this parameter.

It is accepted that to bias future exploration of a planet, terrestrial organisms must be spread out in large numbers over a large area of the planet. Also, conditions favorable to growth are considered to be present in only discrete locations, referred to as micro-environments. Contamination was therefore defined as the proliferation of micro-environments which have been infected by terrestrial organisms. The above definition provided a basis for structuring a sequence of events which lead to proliferation of infected micro-environments from a single organism.

During this reporting period a model consisting of this sequence of events has been constructed. The purpose of the model is to identify and relate events which are relevant to microbial proliferation. It was assumed that these events are mutually independent and that proliferation can only be attained if the complete sequence occurs. The likelihood, or probability, of simultaneously exceeding critical probability thresholds for the sequence was defined as the probability of proliferation (probability of growth).

Two models were developed which differ with respect to the assumption of whether a single infection does, or does not, lead to proliferation. The models are closely related in that the single infection model is a one-generation version of the proliferation model (multi-generation). The main difference between the models is that the single infection model assumes contamination as a direct result of a single colony being formed while the proliferation model sets critical values for the rate of colony growth and additional colonization necessary for contamination.

The intent was to establish which of the models is more compatible for estimation purposes with currently available data. Also, it is necessary to find out which of the two models is more conservative under a variety of assumptions.

During the next reporting period it is planned to document the proliferation model and to identify its potential utility.

4. System Contamination Model

A sterilization implementation systems model was conceived in earlier work[5]. This model quantitatively interrelates the many factors

[5] Schalkowsky, S.; and Kline, R.: Analytical Basis for Planetary Quarantine. Tech. Report, Nov. 1968.

which must be enumerated in evaluating proposed dry heat sterilization programs for determining the preferred approach[6]. The model identifies and accounts for all likely events which can influence the probability of satisfying the specified mission contamination constraint.

The current version of this model includes consideration of component heat soaks, flight acceptance heating of subassemblies, terminal sterilization, recontamination during assembly, terminal velocity characteristics, lander breakup, release through erosion and probability of growth on the planet.

Its usefullness in assessing the sterilization program proposed for Viking '75 can be significantly enhanced through two revisions. First, the flight acceptance subassembly heating function will be supplemented with a system flight acceptance cycle to agree with the program now proposed for the Viking '75. This change will influence the terminal sterilization constraints, since to the extent that surfaces are not remated subsequent to the systems flight acceptance cycle, mated contamination will not govern in the establishment of terminal cycle parameters. The second change requires the substitution of the more complete probability of release model (discussed in Section IV).

We plan to effect these changes in the systems model and exercise this model in an attempt to bound the minimum biologically-justifiable requirements for the sterilization of the Viking lander capsule.

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[6] Schalkowsky, S.; Kline, R.; and DeGraff, E.: Effect of Microbial Release Probabilities on Spacecraft Sterilization Requirements. Interim Report, (contract NASw-1558), Exotech Inc., Systems Res. Div., Aug. 1968.

VI. ORGANIC CONSTITUENT INVENTORY FOR PLANETARY FLIGHT MISSIONS

A. Objective

The purpose of this task is to develop alternative designs for an information system concerning earth-originated organic chemical contamination on other planets in order to minimize the risk of confusing the results of analysis of planetary material samples, the approach for this task was described in detail in the First Quarterly Report.

B. Progress

Communication was established with twelve members of the Viking Project Science Team to develop insights to the potential contamination problems and the value of an information system for dealing with those problems. Six responses voiced concern over the contamination problem and indicated a need for some control of contaminants and an information service in support of experimenters. As was expected the interested responses represent the science areas of biology, molecular analysis of surface material and lower atmosphere, water mapping, thermal mapping and soil magnetic and mechanical properties.

The activity within the Viking Project to implement chemical contamination control plans is relevant to this task. We are presently engaged in developing coordination and cooperation with, and through, the Project Office to ensure that this task benefits as much as possible by related ongoing studies and planning.

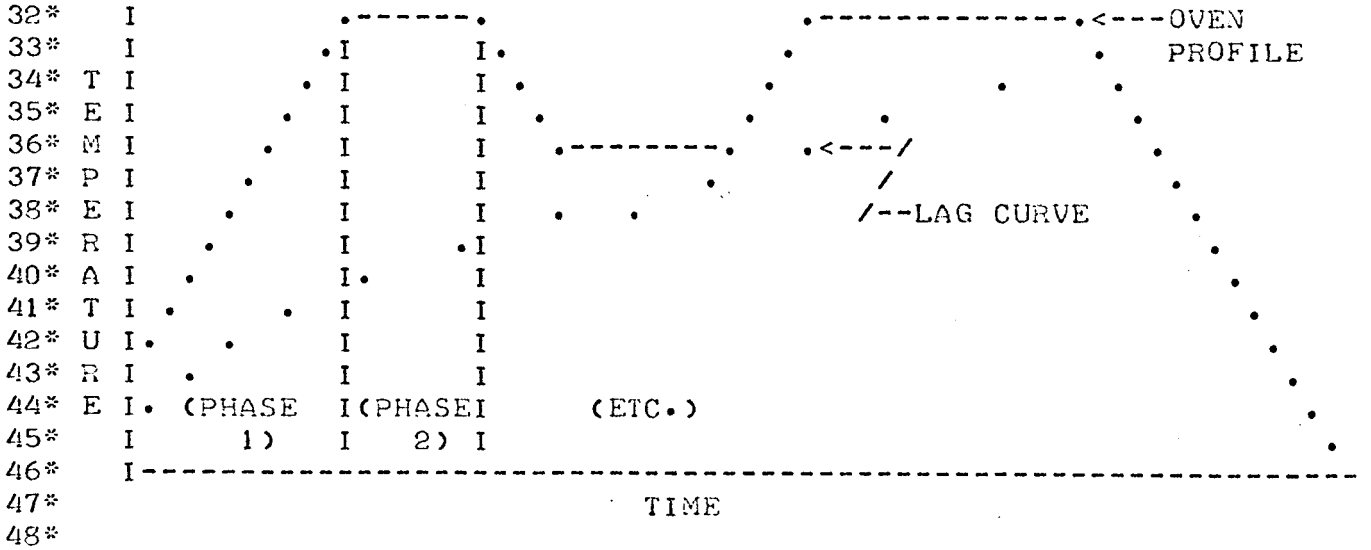
Recommendations for procedures to treat the problems of planetary contamination by terrestrial chemical constituents will be completed during the next reporting period.

APPENDIX A

COMPUTER PROGRAM AND FLOW CHART

FOR STERILIZATION THERMAL DYNAMICS MODEL

```
10*                SPACECRAFT STERILIZATION OVEN PROFILE
11*                ---------- ------------ ---- -------
12*      EXOTECH SYSTEMS, INC.                          JUNE-JULY 1970
13*      THIS PROGRAM ACCEPTS A DEFINED OVEN PROFILE AND THERMAL
14*   LAG CONSTANTS AND COMPUTES THE ACCUMULATED LETHALITY 'SEEN'
15*   BY SPORES ON SPACECRAFT COMPONENTS WITH VARING TIME LAGS.
16*   IT IS OBVIOUS THAT TIME LAG IS PROPORTIONAL TO THERMAL INERTIA.
17*   (NOTE: TAU=0 ==> NO LAG OR SURFACE COMPONENT). MARGINAL LETHALITY
18*   (DIFFERENCE BETWEEN SURFACE AND BURIED LETHALITY), FINAL
19*   INTERNAL TEMPERATURE AND TIME SPENT IN OVEN ARE ALSO COMPUTED.
20*   THE STERILIZATION CRITERION IS THAT THE INTEGRATED LETHALITY
21*   EXCEEDS 'LPARM' DECADES OF POPULATION REDUCTION.
22*
23*      TERMS:
24*         OVEN PROFILE-THE POLYGONAL LINE TIME-PLOT OF OVEN
25*                      TEMPERATURE.
26*         PROFILE PHASE-ONE SEGMENT OF THE POLYGONAL LINE
27*                       OVEN PROFILE.
28*         LETHALITY-KILLING OR REDUCTION IN BIO-LOAD.
29*         THERMAL LAG-TIME LAG OF TEMPERATURE OF HIGH THERMAL
30*                     INERTIA (BURIED) PARTS.
31*
```

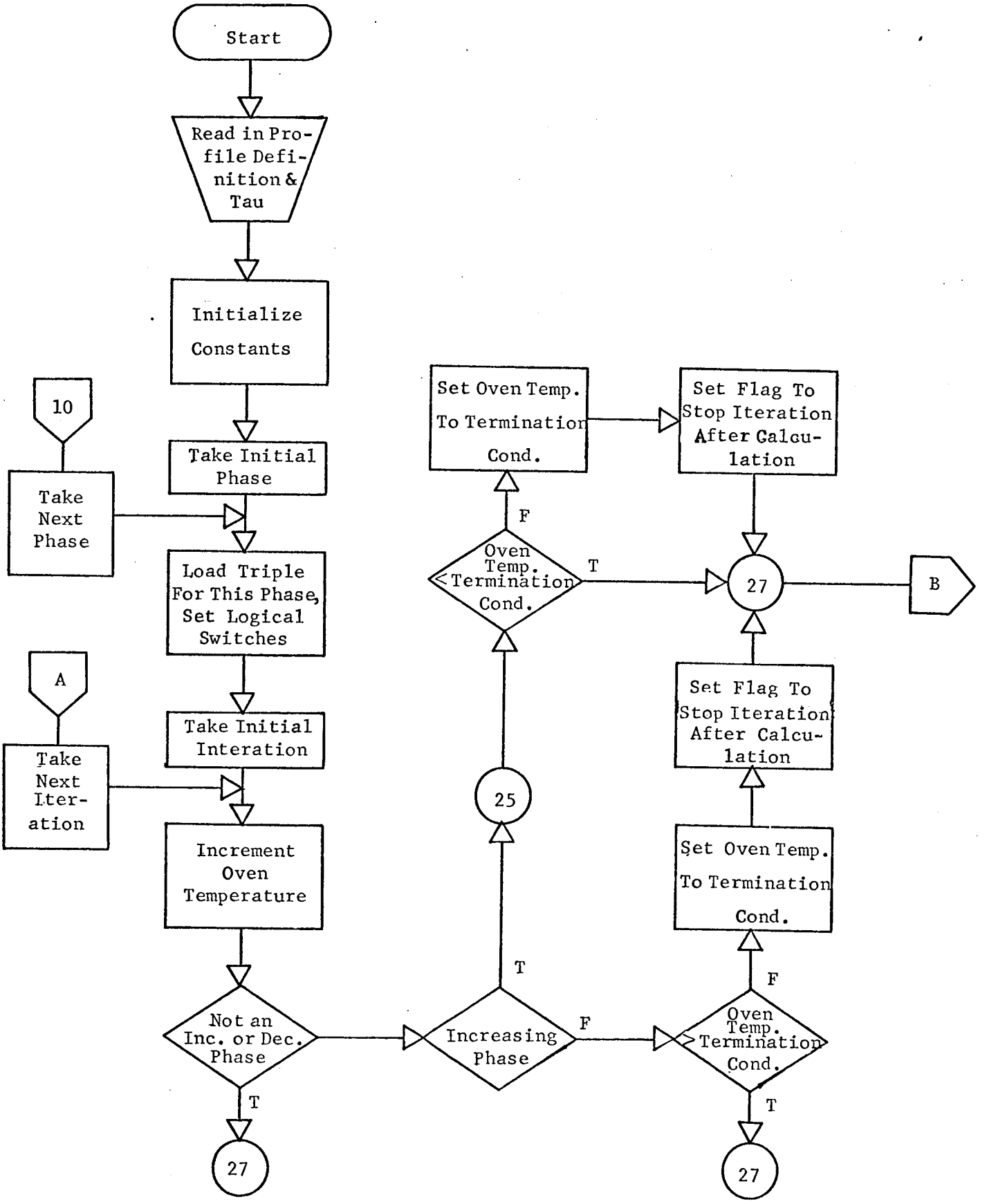


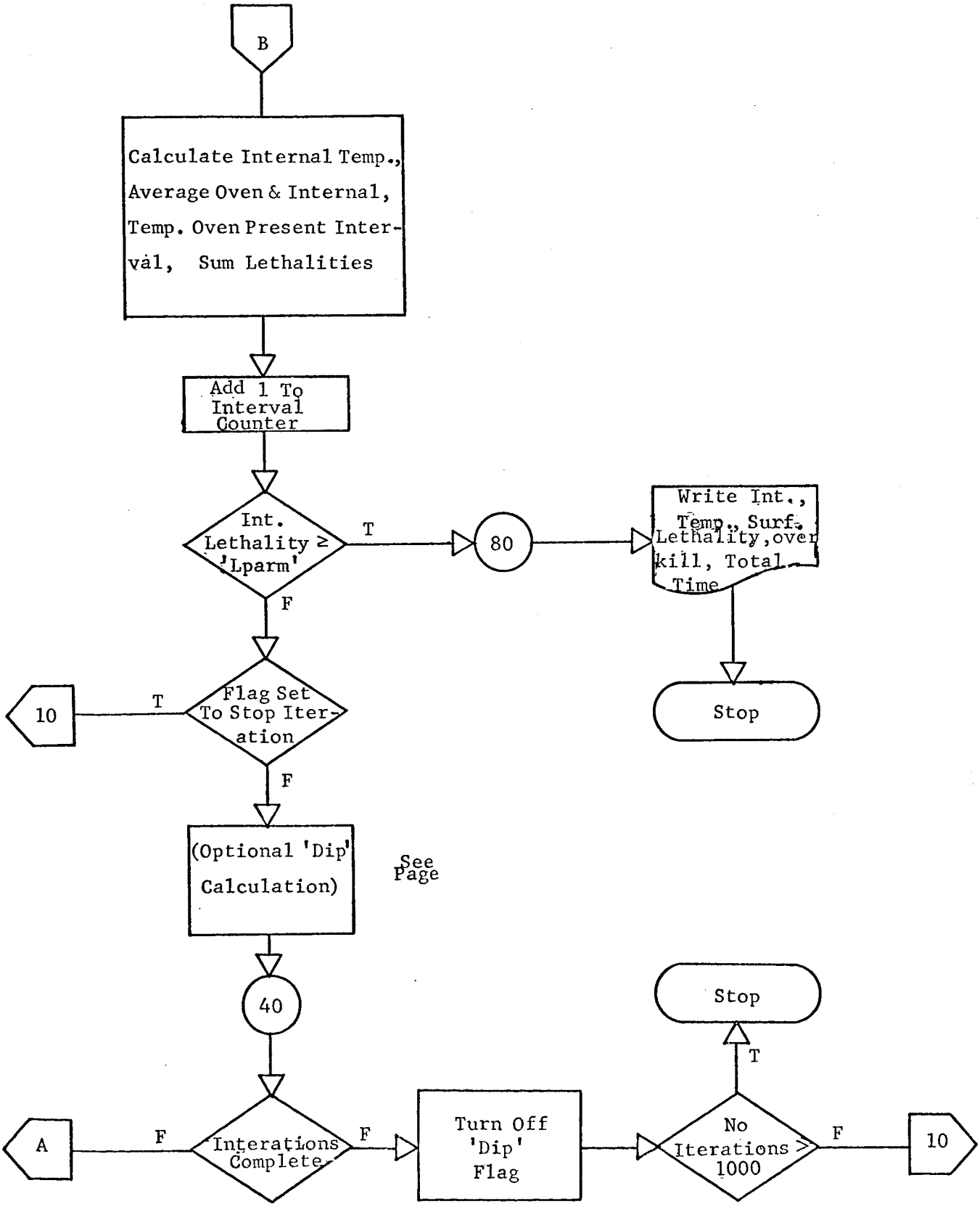
```
49*     EACH PHASE OF THE PROFILE IS CHARACTERIZED BY A TRIPLE
50*  (E.G. (A,B,C)), WHERE:
51*     A = OVEN TEMPERATURE INCREMENT (I.E. NUMBER OF DEGREES
52*         CHANGE PER TIME INTERVAL)
53*     B = MAXIMUM NUMBER OF TIME INTERVALS IN THIS PHASE.
54*     C = PHASE TERMINATION CONDITION (E.G. IF A <> 0, C IS
55*         TEMPERATURE TO WHICH OVEN IS TO BE INCREASED (DECREASED)
56*         DURING THIS PHASE.  IF A = 0, C IS NOT USED BUT
57*         IF THE OPTIONAL ('.') STATEMENTS ARE COMPILED,
58*         THE PROGRAM CREATES 5 OR 10 DEGREE DIPS IN THE PROFILE
59*         AFTER 125 DEGREES HAS BEEN REACHED PROVIDED INTERNAL
60*         TEMPERATURE IS MORE THAN 10 DEGREES BELOW OVEN.)
61*     NOTE:  A 5 DEGREE DIP IS PERFORMED IF 110<INTEMP<115.
62*            A 10 DEGREE DIP IS PERFORMED IF INTEMP<110.
63*
64*     PROGRAM VARIABLES:
65*          OVTEMP = OVEN TEMPERATURE
66*          INTEMP = LAG(INTERNAL) TEMPERATURE
67*          TIME   = LENGTH OF TIME FOR EACH STEP
68*          TAU    = THERMAL LAG PARAMETER
69*          SUM1   = SUM OF ZERO LAG LETHALITY
70*          SUM2   = SUM OF HIGH THERMAL LAG LETHALITY
71*          LPARM  = THE NUMBER OF DECADES REDUCTION TO BE ACHIEVED
72*                   IN THE BIO-LOAD.
73*          INITO  = INITIAL OVEN TEMPERATURE
74*          INITI  = INITIAL INTERNAL TEMPERATURE
75*          T2     = PREVIOUS INTERNAL TEMPERATURE
76*          T3     = AVERAGE INTERNAL TEMPERATURE OVER PRESENT INTERV.
77*          T4     = AVERAGE OVEN TEMPERATURE OVER PRESENT INTERVAL
78*          PHASE  = PHASE COUNTER
79*          INTERV = TIME INTERVAL COUNTER
80*          OVINCR(N)  = OVEN INCREMENT FOR N TH PHASE
81*          MAXTIM(N)  = MAXIMUM NUMBER OF ITERATIONS FOR N TH PHASE
82*          TERCON(N)  = TERMINATING CONDITION FOR N TH PHASE
83*          OVI,MAX,TER = TEMPORARY VARIABLES FOR OVINCR,MAXTIM,
84*                        AND TERCON, RESPECTIVELY
85*          PHMAX  = NUMBER OF PHASES IN PROFILE
```

```
86*
87*
88*              S  O  U  R  C  E     C  O  D  E
89*
90*
100           DIMENSION MAXTIM(50),TERCON(50),OVINCR(50)
150           LOGICAL UP,DOWN,OUT,DIP
200           INTEGER PHMAX,PHASE
300           REAL INITO,INITI,INTEMP,LPARM
400           DATA INITO,INITI/70.,45./
450           DATA TAU,LPARM/1.2,5.88/
497*
498*      READ IN PROFILE DEFINITION
499*
500           READ(9,100) PHMAX
600           DO 5 I=1,PHMAX
700    5      READ(9,110) OVINCR(I),MAXTIM(I),TERCON(I)
710           WRITE(9,120)
720           READ(9,130) TAU
797*
798*      INITIALIZE CONSTANTS
799*
800           INTERV=0
810           IMAX=0
825           SUM1=0.0
850           SUM2=0.0
900           TIME=.2
950           INTEMP=INITI
1000          OVTEMP=INITO
1100          PHASE=0
1150          DIP=.FALSE.
1197*
1198*      ACCEPT TRIPLE DEFINING NEXT PHASE OF PROFILE
1199*
1200   10     PHASE=PHASE+1
1300          IF(PHASE.GT.50) GO TO 90
1400       OVI=OVINCR(PHASE)
1500          MAX=MAXTIM(PHASE)
1600          TER=TERCON(PHASE)
1697*
1698*      SET LOGICAL VARIABLES DESCRIBING THIS PHASE
1699*
1700          OUT=.FALSE.
1800          UP=.FALSE.
1900          DOWN=.FALSE.
2000          IF(OVI.EQ.0.) GO TO 20
2100          IF(OVI.GT.0.) UP=.TRUE.
2200          IF(OVI.LT.0.) DOWN=.TRUE.
```

```
2296*
2297*     ITERATE THROUGH THE PHASE, CALCULATING OVEN AND THERMAL
2298*     LAG TEMPERATURES AND SUMMING THE LETHALITY
2299*
2300 20      DO 40 ITIME=1,MAX
2400          OVTEMP=OVTEMP+OVI
2500          IF(.NOT.(UP.OR.DOWN)) GO TO 27
2600          IF(UP) GO TO 25
2700          IF(OVTEMP.GT.TER) GO TO 27
2800          OVTEMP=TER
2900          OUT=.TRUE.
3000          GO TO 27
3100 25       IF(OVTEMP.LT.TER) GO TO 27
3200          OVTEMP=TER
3300          OUT=.TRUE.
3400 27       T2=INTEMP
3500          INTEMP=OVTEMP-(OVTEMP-T2)*EXP(-TIME/TAU)
3600          T3=(INTEMP+T2)/2.
3700          T4=OVTEMP+OVI/2.
3800          SUM1=SUM1+TIME*10**((T4-125.)/21.)
3900          SUM2=SUM2+TIME*10**((T3-125.)/21.)
4000          INTERV=INTERV+1
4100          IF(SUM2.GE.LPARM) GO TO 80
4200          IF(OUT) GO TO 10
4297*
4298*     ******OPTIONAL STATEMENTS FOR 'DIP' CALCULATION******
4299*
4300.         IF((UP.OR.DOWN).OR.DIP) GO TO 40
4400.         IF((125.-INTEMP).LT.10.) GO TO 40
4500.         IF((125.-TNTEMP).LT.15.) GO TO 30
4600.         TERCON(PHASE+1)=115.
4700.         WRITE(9,150)
4800.         GO TO 35
4900. 30      TERCON(PHASE+1)=120.
4950.         WRITE(9,160)
5000. 35      OVINCR(PHASE+1)=-10.
5010.         MAXTIM(PHASE+1)=10
5020.         OVINCR(PHASE+2)=0.
5030.         MAXTIM(PHASE+2)=1
5040.         TERCON(PHASE+2)=0.
5050.         OVINCR(PHASE+3)=10.
5060.         MAXTIM(PHASE+3)=10
5070.         TERCON(PHASE+3)=125.
5080.         DIP=.TRUE.
5100.         GO TO 10
5197*
5198*     ******END OF OPTIONAL STATEMENTS******
5199*
5200 40       CONTINUE
```

```
5250          DIP=.FALSE.
5300          IMAX=IMAX+MAX
5500          IF(IMAX.LT.1000) GO TO 10
5600          WRITE(9,210) IMAX
5650          STOP
5697*
5698*     PRINT    INTERNAL TEMP.,SURFACE LETHAL.,OVER-KILL,TOTAL TIME
5699*
5700  80      S=SUM1-SUM2
5800          C=.2*FLOAT(INTERV)
5900          WRITE(9,200) INTEMP,SUM1,S,C
6000          STOP
6100  90      WRITE(9,220)
6200          STOP
6300  100     FORMAT(I2)
6400  110     FORMAT(F4.0,I3,F4.0)
6440  120     FORMAT(//'INPUT TAU IN FOLLOWING FORMAT:  ##.# HRS.')
6450  130     FORMAT(F4.1)
6500  150     FORMAT(//'TEN DEGREE DIP')
6600  160     FORMAT(//'FIVE DEGREE DIP')
6700  200     FORMAT(/4(F7.2,4X))
6800  210     FORMAT(///'CONDITION NOT MET IN ',I4,' ITERATIONS.')
6900  220     FORMAT(///'!!!!DIMENSION OVER-RUN!!!!')
7000          END
```


Start
Read in Profile Definition & Tau
Initialize Constants
10
Take Next Phase
Take Initial Phase
Load Triple For This Phase, Set Logical Switches
A
Take Next Iteration
Take Initial Interation
Increment Oven Temperature
Not an Inc. or Dec. Phase
T
27
Increasing Phase
F
T
25
Set Oven Temp. To Termination Cond.
F
Oven Temp. < Termination Cond.
T
Set Flag To Stop Iteration After Calculation
27
B
Set Flag To Stop Iteration After Calculation
Set Oven Temp. To Termination Cond.
F
Oven Temp. > Termination Cond.
T
27


B
Calculate Internal Temp., Average Oven & Internal, Temp. Oven Present Interval, Sum Lethalities
Add 1 To Interval Counter
Int. Lethality ≥ 'Lparm'
T
80
Write Int., Temp., Surf. Lethality, over kill, Total Time
Stop
F
10
T
Flag Set To Stop Iteration
Stop
F
(Optional 'Dip' Calculation)
See Page
40
Stop
T
A
F
Interations Complete
F
Turn Off 'Dip' Flag
No Iterations > 1000
F
10

OPTIONAL 'DIP' CALCULATION